Comparative Study Of The Mechanical Characteristics Of Dental Implants Made From Biomaterials Covered With DLC Depositions

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***Abstract* – Nanostructures and nanostructured materials development has opened important expectative in multiple fields, however, one of them, with important direct impact on the society is the medicine.**

In this paper is presented a comparative study of the mechanical properties of titanium used for dental implants covered or not with an ultra thin DLC (Diamond Like Carbon) film deposition. Evaluation was focused on determining the number of cycles until failure in dynamic fatigue testing according to SR EN ISO 14801: 2008 and static compression strength according to SR EN ISO 6892-1:2010, for dental implants made of pure titanium covered/not covered with a layer of DLC. In order to make a comparison between covered and uncovered specimens, two of them were covered with DLC depositions, and other two without deposition. The obtained results show the improvement of the mechanical properties.

Keywords – biomaterials, mechanical properties, nanodepositions.

I. INTRODUCTION

Bone is one of the most replaced parts in the human body. The current treatment option is implantation. Implants with scaffolds have to provide anchorage of cells and play an important role in bone regeneration. The materials need to be biocompatible and provide appropriate mechanical support similar to the natural bone.

Austenitic stainless steel, titanium and its alloys are widely used for biomedical applications, including devices for bone fixation and partial/total joint replacement because they are corrosion resistant metals with the required mechanical strength and biocompatibility. They are referred as “first generation of biomaterials” [1] in the technical studies.

These biomaterials for implants are not osseoconductive and their surface does not have structural and functional connection with the living bone that can enable reaction with the surrounding tissues, referred as osseointegration. Furthermore, they tend to release a high concentration of metal ions into the body, which is likely to have toxic effects on bone cells, leading to failure and may inhibit formation of bone (osteogenesis).

“The second generation of biomaterials” are bio-active ceramics such as calcium phosphate and bioactive glass and was developed as possible alternative to the first generation of metallic biomaterials. These materials have the ability to promote bone apposition with bone tissues without fibrous encapsulation, thereby leading to osseointegration.

One of these materials is calcium carbonate-containing apatite layer (CA) which is chemically similar to the inorganic mineral phase of a natural bone and is considered important for the osseointegration process. However, this class of bioceramics exhibits low bending strength (42–200 MPa) and is brittle, restricting their use in load bearing applications [2].

The implant must interact with the adjacent tissue, to permit the bone regeneration and the growth of osteogenic cells.

The texture of surface implants is very important in the osseointegration process. So it is necessary to have a porous surface to permit the osteoblasts cells proliferations better than the osteofibre ones.

Studies show that classic biomaterials with carbon nano depositions present acceleration of bone cell function in comparison with materials without such covering. [3]

The deposition of the DLC film was made using thermionic vacuum arc method (TVA).

The method (TVA) is based on evaporating the coating material by an indirectly heated cathode surrounded by a Wehnelt cylinder. [4]

The evaporation material state is obtained by heating it with thermal electrons generated by the circular shape filament indirectly heated and situated above the anode. The used anode was a carbon rod with a 6mm diameter.

Due to large energy dissipated in the plasma volume, the deposited material is completely dispersed without drops. The obtained film is very fine and under certain conditions appears as a nanostructures deposition.

The thickness of deposited layer was 150nm, and the deposition was made at Ovidius Constanta University.

II. MATERIALS PROPERTIES

The ideals proprieties of materials for implants are:

- Hard resistance at static and dynamics loads which appears in the implant place;
- Resistance at alternative bending tests;
- Wear resistance;
- Corrosion resistance at the body fluids;
- Chemical and thermal stability;
- Unaffected by X ray radiation;
- Undistorted by manufactured process;
- Low price;
- To be reproducible;
- Non-toxic and no-allergenic in contact with body fluids;
- Bio tolerant at the interface tissue-materials.

III. TEST SPECIMENS

In order to characterize the mechanical properties of coatings with nanostructured materials obtained by DLC deposition, dental implants were used as samples (see fig. 1), made from pure titanium material, which is one of the most used materials for implants manufacturing.

For the tests were use four specimens, two uncovered and two with ultra thin DLC deposition using thermionic vacuum arc method (TVA).

The used dental implants consisted of tapping component with a diameter of 3.2mm and 13.2 mm long and abutment with conical surface (at an angle of 10°), for connecting with the assembly, total length of 9.5 mm and M2 threaded fastener (see fig.2). The parts were made of pure titanium 99.9 %.

Fig. 1: Dental implant assembly

Fig. 2: Tapping component and abutment

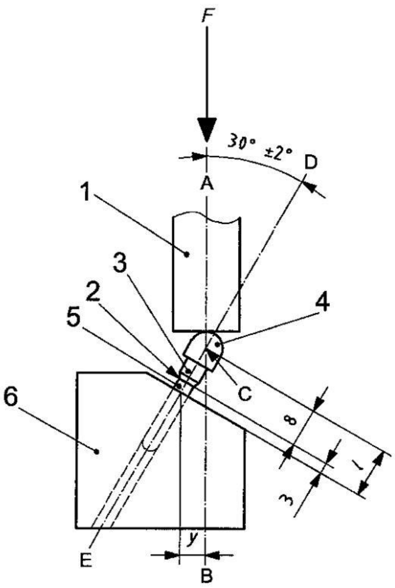


Fig. 3: Testing configuration according to SR EN ISO 14801:2008

IV. LOADING GEOMETRY

Fatigue testing was performed by simulation of the functional loading on the endosseous dental implant, with abutment and tapping component, in the worst possible operating conditions.

To comply with the requirements of the fatigue test method specified by EN ISO 14801:2008, a hemispherical part with a radius of 2.5 mm was mounted on the implants subjected to this test and the assembly was fixed on the machine's table Instron 8872 type in the configuration presented in figure 3.

Notations in the figure are:

1. Loading device which should allow free movement transverse to loading direction;
2. Nominal bone level;
3. Connecting part (abutment);
4. Hemispherical loading member;
5. Dental implant body;
6. Clamping device.

Dental implant assembly with no pre-angled connecting part and hemispherical member must be clamped so that its axis makes an angle of 30 ° ± 2 ° with the loading direction of the testing machine (see fig. 3.)

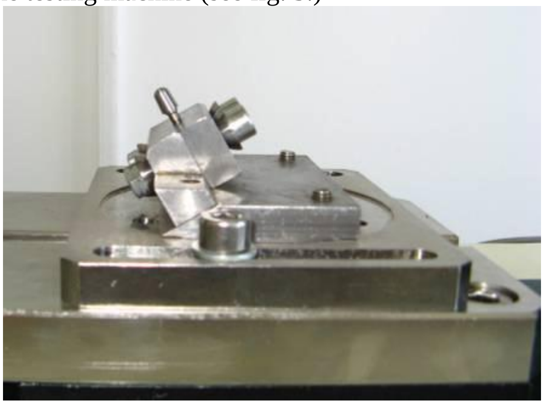


Fig.4: Clamping and positioning device

According to the scheme in Figure 3, load center "C" is at the intersection between the longitudinal axis of the assembly and loading axis of the testing machine and must be at a distance *l*=11 mm from the surface of the clamping device.

In order to ensure the requirements of SR EN ISO 14801:2008 a clamping and positioning device for the sample was designed (see fig. 4.).

V. MECHANICAL PROPRIETIES EVALUATION

The testing method applied to specimens in order to characterize the mechanical properties is fatigue test.

Failure of biomedical implants is dominated by fatigue or fatigue related failure such as fretting fatigue which is affected by various factors (mean stress, frequency or stress cycling, etc.).

For determination of mechanical resistance the dental implants specimens were submitted to dynamic fatigue tests.

The purpose of this comparative study is to determine the number of cycles until failure in fatigue testing according to SR EN ISO 14801: 2008 and static compression strength according to SR EN ISO 6892-1:2010, for dental implants made of pure titanium covered/not covered with a layer of DLC.

The obtained results were compared in order to observe the influence of the covering with nanostructured layers upon mechanical characteristics of the tested parts.

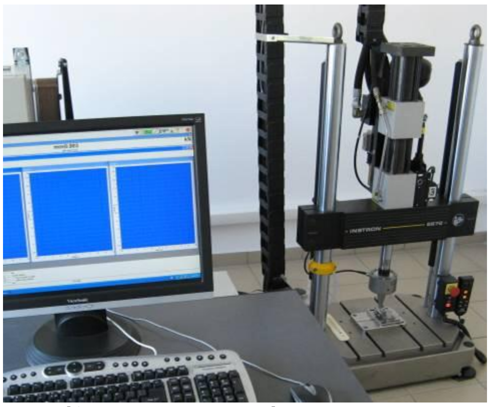
To determine the value of maximum loading force for dynamic fatigue tests, the standard recommends first a static test to determine the compression strength of the sample, which is oriented in the same position as in the case of dynamic application.

For the compression strength determination, tests were made on a static testing machine Hounsfield H10KT type (fig.5 a) and the dynamic fatigue tests were made on an Instron 8872 testing machine (fig.5 b).

VI. RESULTS AND DISCUSSION

The characteristic curves obtained in compression strength determination are presented in the figure 6.

a) Static testing machine Hounsfield H10KT



b) Dynamic testing machine Instron 8872

Fig. 5: Testing machines

The maximum loading force was 318,4N for the uncovered specimen while, for the DLC covered specimen, the force increased up to 332N.

On the characteristic curves the absence of the material yielding can be observed for the specimen with nanostructured layer deposition, suggesting an improvement of the elastic properties.

For the dynamic test the maximum loading force was established to 200N representing about 63% of maximum strength obtained from static loading.

Force was applied unidirectional and varied sinusoidal and was ranged between 200 N and 20N (minimum value equal to 10% of maximum value) in order not to lose contact between the loading device and the sample. The loading frequency was set at 15 Hz.

The test ended at the sample failure and the software of the testing machine recorded automatically the cycle number at which failure occurred.

The recorded number of cycles for the uncovered sample was 1,282,736 and for DLC covered sample was 1,346,424 cycles.

VII. CONCLUSIONS

The mechanical strength of the implant scaffolds is rather important in applications where load bearing is required, such as matrices to promote bone tissue growth.

A major problem with titanium implants is that osseointegration by way of its natural oxide TiO_2 is a long process.

As a result, implant fixation takes place through an accumulation of fibrous soft tissue (rather than hard bone), which over time results in loosening of the implant, causing discomfort and eventual failure.

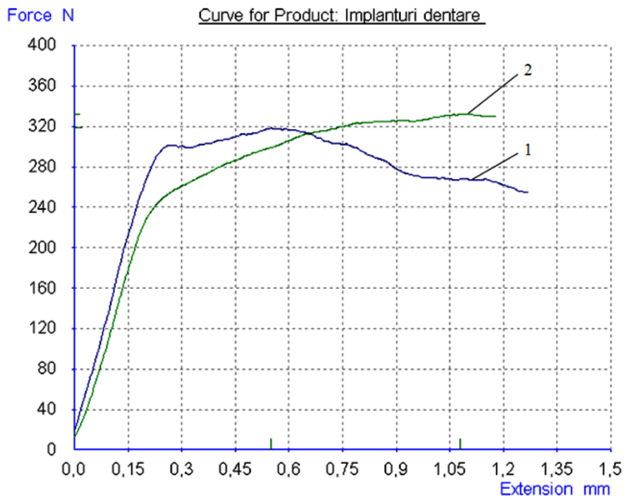


Fig. 6: Characteristic curves in the compression test1-uncovered specimen; 2- DLC covered specimen

In order to prevent this inconvenience a ultra thin layer of DLC can be deposited on the implant, improving also the wear resistance and lowering the friction coefficient.

From the obtained results we can see that by surface treating due to nanometric deposition of carbon fibres, endurance limit and compressive strength shows a slight improvement. DLC coatings with biocompatible properties lead to improved endurance limits of the endosseous implants.

Another improvement achieved by coating with DLC film is the increase of the elasticity range observed on the characteristic curves for the compression test.

All these specific properties of DLC coatings are very suitable for improving the performance of medical devices and micro-mechanical devices for biomedical applications.

The aim of dental implant is to achieve at least the same percentage of elongation under the same stress in an implant-bone-combination. The increase of the implant elasticity in order to be similar to that of the bone is the most promising way to achieve the desired adapted implant elasticity.

Due to the mentioned above considerations the obtained increased elasticity of the specimens is a favourable effect. This can lead to the increase of the implant's life-time [5].

In the present paper the possibility of improving mechanical properties of the conventional biomaterials was demonstrated by mechanical testing of coated and uncoated specimens leading to greater elasticity, compression strength and better fatigue strength.

The future researches can be orientated to improve the surface depositing process in order to obtain a better homogeneity of the specimen and repeatability of the results.

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